Eimac®

EITEL-McCULLOUGH, INC.
SAN CARLOS · CALIFORNIA

NUMBER 5

TUBE PERFORMANCE COMPUTOR

DETAILED INSTRUCTIONS

TUBE PERFORMANCE COMPUTOR FOR R-F AMPLIFIERS (CLASS B, C, AND FREQUENCY MULTIPLIERS)

It is quite easy to make a close estimate of the performance of a vacuum tube in radio-frequency power-amplifier service, or an approximation in the case of harmonic-amplifier service. Such estimates will give r-f output power, d-c input power, grid driving power, and all d-c current values.

These estimates can be made easily by using the Eimac Tube Performance Computor and the characteristic curves of a tube, plotted on plate-voltage/grid-voltage coordinates (constant-current curves). Only the ability to multiply figures taken from the curves, by means of the computor, is required.

By graphically laying out the trace of the plate and grid voltages as they rise and fall about the applied d-c plate voltage and d-c grid bias, a clear understanding of the action taking place within a tube is possible. With such an understanding the operating conditions can be altered readily to suit one's particular requirements.

Simple Action in Class-C R-F Amplifiers

In an amplifier a varying voltage is applied to the control grid of the tube. Simultaneously the plate voltage will vary in a similar manner, due to the action of the amplified current flowing in the plate circuit. In radio-frequency applications with resonant circuits, these voltage variations are smooth sine-wave variations, 180° out of phase (as the grid voltage rises and becomes *more* positive, the plate voltage falls and becomes *less* positive) as indicated in Fig. 1. Note how these variations center about the d-c plate voltage and the d-c control-grid bias.

Let us now see how such variations of the plate and grid voltages of a tube appear on the constant-current curves of a tube. In Fig. 2 these variations have been indicated next to the plate-voltage and grid-voltage scales of a typical constant-current curve. At some instant of time, shown as "t" on the time scales, the grid voltage has a value which is the point marked "eg" on the grid-voltage sine wave. If one now finds the point on the tube curves corresponding to these values (where a line drawn from "eg" and a line drawn from "ep' cross) he will be at point A in Fig. 2. As the values of grid voltage "eg" and plate voltage "ep" vary over the r-f cycle, the point A moves up and down a line, which in the case of the normal r-f power amplifier is a straight line. This line is called the "Operating Line."

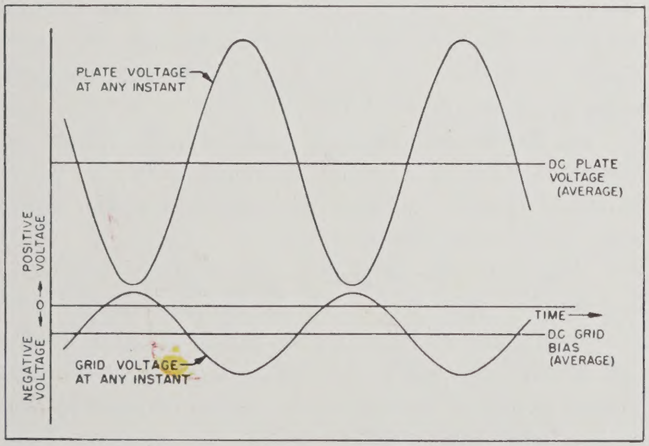

Figure 1

Any point on the operating line (when drawn on constant-current curves as in Fig. 2 or Fig. 4) tells the instantaneous values of plate current, screen current, and grid current which must flow when those particular values of grid and plate voltage are applied to the tube. Thus by reading off the values of the currents and plotting them against the time "t", one can obtain a curve of instantaneous values of plate and grid current. See Fig. 3.

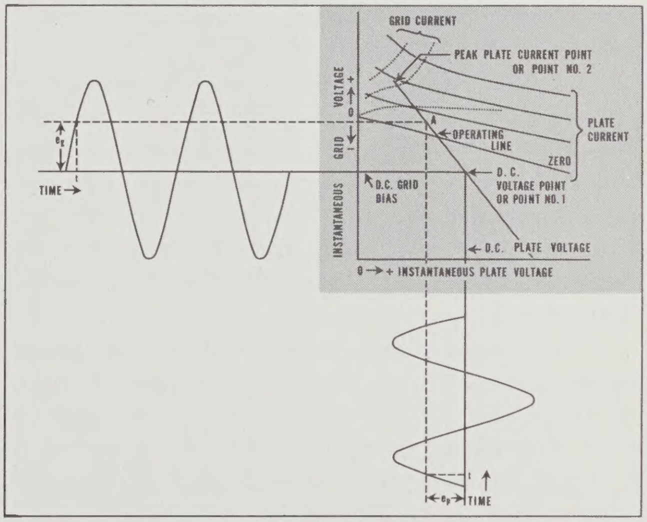
GRID CURRENT
PEAK PLATE CURRENT POINT OR POINT NO. 2
PLATE CURRENT
ZERO
A
OPERATING LINE
D. C. VOLTAGE POINT OR POINT NO. 1
D.C. GRID BIAS
INSTANTANEOUS GRID VOLTAGE
+
0
-
e_g
t
TIME
D.C. PLATE VOLTAGE
0 → + INSTANTANEOUS PLATE VOLTAGE
e_p
TIME

Figure 2

If we analyze the plate and grid-current values shown, we can predict that they will cause a d-c ammeter to show a particular reading. This is called the d-c component of the current. Also, we can predict that if the plate current flows through a properly loaded resonant r-f circuit a certain amount of radio-frequency power will be delivered to that circuit. If the circuit is tuned to the fundamental frequency (same frequency as

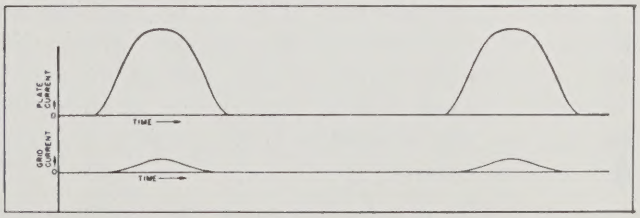

Figure 3

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the r-f grid voltage) the power delivered will be due to the fundamental, or principal, radio-frequency component of plate current. If the circuit is tuned to a harmonic of the grid-voltage frequency, e.g., two or three times the frequency, the power delivered will be due to a harmonic component of the plate current.

Use of the Eimac Tube Performance Computor

The Eimac Tube Performance Computor gives us the means to make these simple calculations. It is a means with which to determine the d-c component, the fundamental r-f component, or the approximate harmonic component of the current flowing in a tube when the tube is operating as a radio-frequency amplifier, and enables one to state what all meter readings will be and to predict the r-f output power and the required driving power. With these factors known we are able to forecast what will happen if any of the operating conditions are changed.

The Eimac Tube Performance Computor is a simple aid to enable one to select suitable values from the characteristic curves of a tube, and by means of simple calculations to forecast the performance of the tube in radio-frequency power amplifiers.

The basic steps are outlined under "Instructions" on the computor. This requires selecting d-c plate and grid-bias voltages, being guided by the typical operating values given on the technical data sheet for the tube type, and by general experience. Next, a suitable "Operating Line" must be chosen on the constant-current curves for the tube type (plotted on grid-voltage/plate-voltage coordinates).

The computor, when properly placed over this operating line, enables one to obtain instantaneous values of the currents flowing at every 15° of the electrical cycle. The formulas given on the computor were derived by Chaffee[1] to give the various average and harmonic components of the resulting currents. Knowing these current component values and the radio-frequency voltage values which are indicated through use of the computor, one can readily calculate the complete performance of the tube.

The fundamental methods of making such computations, and the considerations necessary to stay within ratings of the tube types while accomplishing various forms of modulation have been covered in the literature, [2, 3, 4, 5, 7]. The method for the case of harmonic-amplifier service is approximate and should be used only for tetrode and pentode tubes where the plate voltage has little effect on the amount of plate current flowing. A more exact method, showing that for harmonic operation the operating line is a simple Lissajou figure, has been described by Brown.[8]

The results obtained by using this computor for power-amplifier service can be applied in combination with the other methods given in the literature to give good accuracy with simpler procedures. The resulting accuracy is well within the normal variation of tube characteristics due to the normal variation in manufacturing dimensions of a tube. Since the published tube curves are only typical of the characteristics to be expected from a particular tube type, the calculated performance is well within the values obtained when different tubes of a given tube type are operated under the assumed conditions.

Example Showing Detailed Use of the Eimac Tube Performance Computor

Radio-Frequency Power Amplifier, Class-C (Telegraphy or FM)

Let us say that we have an Eimac 4-65A tetrode and want to make it work effectively. Also, let us assume that we have a 2000-volt d-c plate power supply available.

Within frequency limits, we know that a tube should be able to run in class-C amplifier service with about 75% efficiency, or in other words to convert 75% of the d-c plate input power into r-f output power. The difference, or 25% of the input power, is dissipated or lost as heat on the plate of the tube. The d-c plate input power is then about four times the power dissipated on the plate.

The 4-65A tetrode has a maximum rated plate dissipation of 65 watts, and, to illustrate performance near the maximum rating, we'll choose an input power four times the dissipation rating, or about 260 watts per tube. At 2000 volts the plate current per tube must then be 130 ma. It is usual practice in the case of tetrodes and the medium or low-mu triodes in class-C amplifier service for the d-c grid-bias voltage to be roughly two or three times the grid voltage necessary to cut off the flow of the plate current. By referring to the curves for the 4-65A, we decide to use a d-c grid-bias voltage of −130 volts.

Let us now locate the "Operating Line" on the constant-current curves for the 4-65A. See Fig. 4. First, mark the point where the d-c grid bias and d-c plate voltage cross. The "Operating Line" must go through this point. Call it point No. 1. Next, we must decide what the peak value of plate current of the tube must be and how low we can let the instantaneous value of plate voltage go when the tube is passing this much current. This is necessary in order to locate the other end of the "Operating Line," point No. 2.

The peak value of plate current in class-C amplifiers usually runs about four times the d-c plate current. The minimum value of instantaneous plate voltage is usually set by the fact that if the voltage is too low, the grid current in triodes and the screen current in tetrodes will be needlessly high, resulting in high grid or screen dissipation. Also, little will be gained as far as output power

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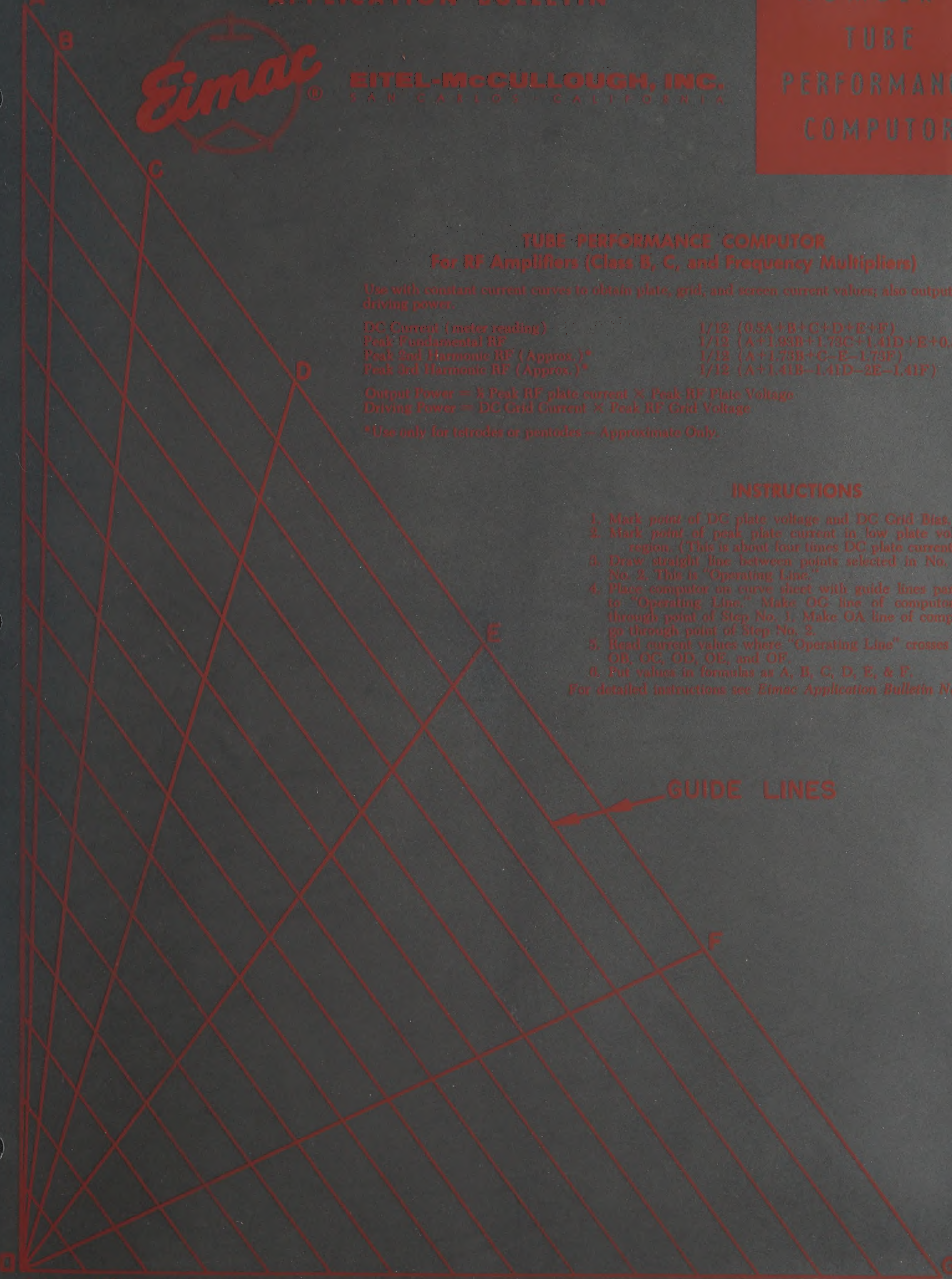

TUBE PERFORMANCE COMPUTOR
For RF Amplifiers (Class B, C, and Frequency Multipliers)

Use with constant current curves to obtain plate, grid, and screen current values; also output and driving power.

DC Current (meter reading)	1/12 (0.5A+B+C+D+E+F)
Peak Fundamental RF	1/12 (A+1.93B+1.73C+1.41D+E+0.52F)
Peak 2nd Harmonic RF (Approx.)*	1/12 (A+1.73B+C−E−1.73F)
Peak 3rd Harmonic RF (Approx.)*	1/12 (A+1.41B−1.41D−2E−1.41F)

Output Power = ½ Peak RF plate current × Peak RF Plate Voltage
Driving Power = DC Grid Current × Peak RF Grid Voltage

*Use only for tetrodes or pentodes — Approximate Only.

INSTRUCTIONS

1. Mark *point* of DC plate voltage and DC Grid Bias.
2. Mark *point* of peak plate current in low plate voltage region. (This is about four times DC plate current.)
3. Draw straight line between points selected in No. 1 & No. 2. This is "Operating Line."
4. Place computor on curve sheet with guide lines parallel to "Operating Line." Make OG line of computor go through point of Step No. 1. Make OA line of computor go through point of Step No. 2.
5. Read current values where "Operating Line" crosses OA, OB, OC, OD, OE, and OF.
6. Put values in formulas as A, B, C, D, E, & F.

For detailed instructions see *Eimac Application Bulletin No. 5.*

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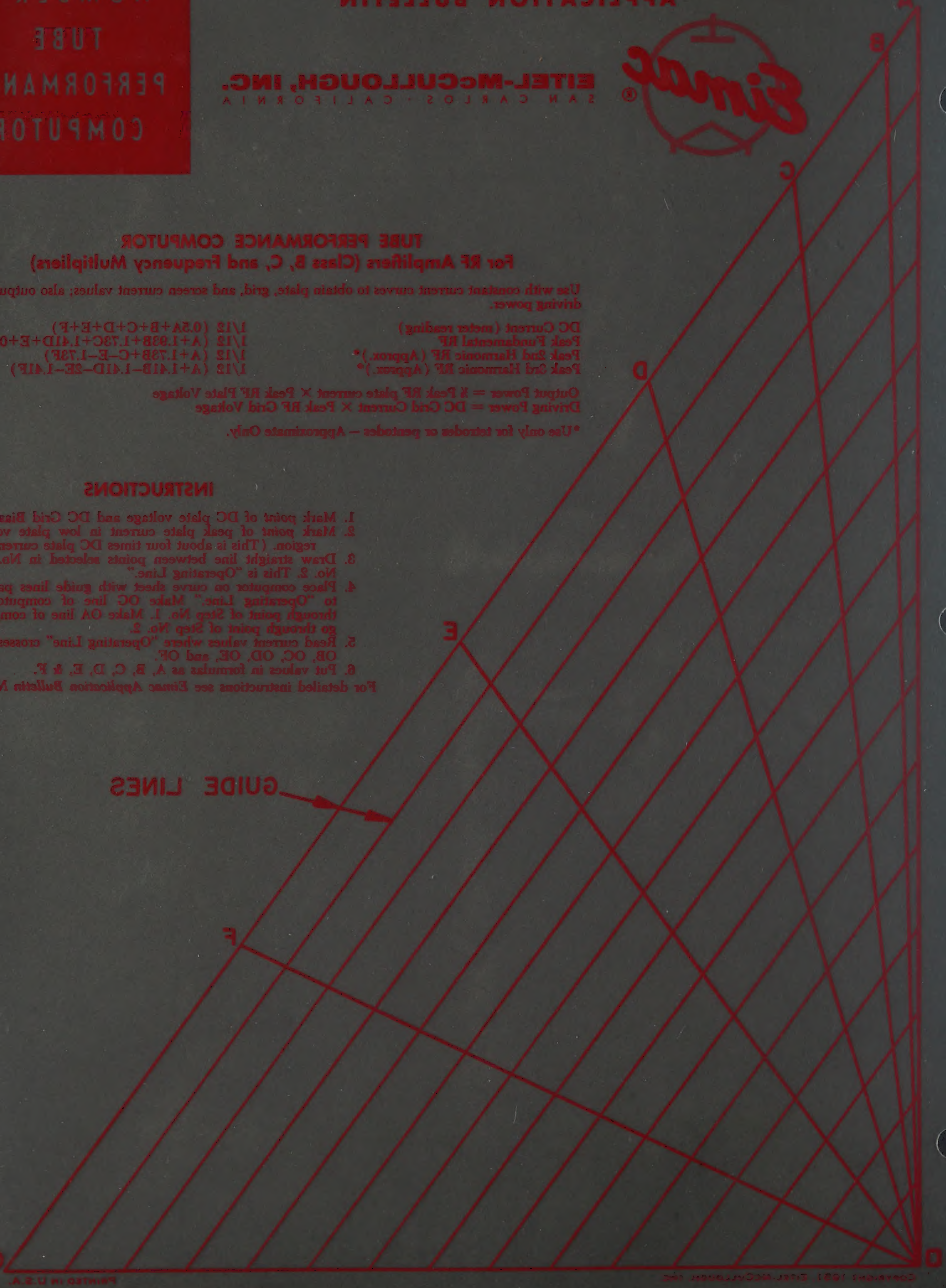

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is concerned. The minimum value of plate voltage is usually in the region where the plate constant-current curves bend upward. See Fig. 4. (In the case of the triode this is near the "diode line," the imaginary line where the instantaneous grid and plate voltages are equal.) The practical procedure in calculating tube performance is to arbitrarily choose point No. 2, complete the calculations, and compare the results.

In the case of the 4-65A let us choose a peak value of plate current about four times the d-c plate current of 130 ma, or 500 ma. Let us choose a minimum instantaneous plate voltage of 250 volts and thus fix the upper end of the "Operating Line." Next, locate this point on the tube curves. This is point No. 2 on Fig. 4. (The plate currents which flow at various combinations of plate and grid voltages are shown by the plate-current lines. The value of current for each line is noted. In-between values can be estimated closely enough for our purposes.) Now draw a straight line between points No. 1 and No. 2. This line is the "Operating Line" and shows the current and voltage values at each instant in the r-f cycle when current is being taken from the tube. (The non-conducting half of the r-f cycle would be shown by extending this line an equal distance on the opposite side of point No. 1. However, there is little use in doing so, because no current flows during this half of the cycle.)

The Eimac Tube Performance Computer can now be used to obtain the meter readings and power values from this "Operating Line." Place the computor on the constant-current curve sheet so that the "guide lines" of the computor are parallel with the operating line. Now slide the computor without turning it until the line OG passes through the d-c voltage point No. 1 and line OA passes through the peak-current point No. 2. *Make sure the guide lines are still parallel to the "Operating Line."*

Note that the lines OB, OC, OD, OE, and OF of the computor all cross over the "Operating Line."

At each point where the lines OA, OB, etc., cross the "Operating Line" we need to determine the instantaneous values of plate current and grid current (and screen current if a tetrode or pentode is used) which are flowing at that particular moment in the r-f cycle. Later, from these key values of current, we will calculate the values of d-c plate current and grid current (and screen current) as well as the r-f components of the plate current.

These current values should be listed for each point where the lines OA, OB, etc. cross the operating line so that they can be combined later to caculate the various tube currents. At points where OF and OE cross, the current values are usually zero for class-C operation.

Now in the example chosen, let us read off the instantaneous plate-current values where these lines cross the "Operating Line." At the point where the line OA crosses the "Operating Line" the plate current is 500 ma.

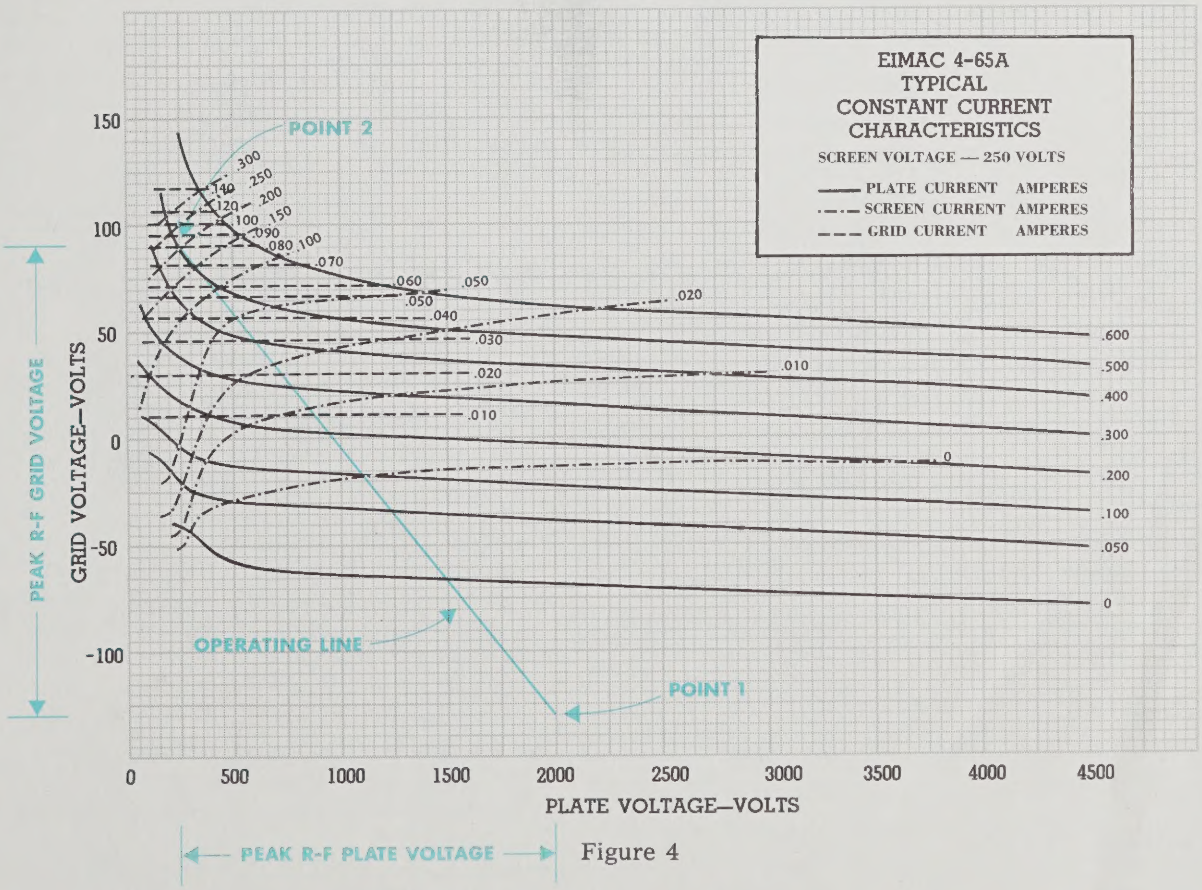

Figure 4

Where OB crosses the operating line the plate current is also 500 ma. At OC the plate current is about 450 ma, OD 300 ma, OE 90 ma, OF and OG 0 ma. Similarily we can see that the instantaneous screen current at the crossing of OA and the "Operating Line" is 200 ma, and the instantaneous grid current is almost 80 ma. Values are read for the other crossings and written down. These values are put in simple columns for calculating:

Crossing of line	Simplified name in Formulas	Instantaneous values of currents		
		Plate	Screen	Control grid
OA	A	500 ma	200 ma	80 ma
OB	B	500	155	70
OC	C	450	60	42
OD	D	300	15	17
OE	E	90	0	0
OF	F	0	0	0

Now in order to obtain the d-c value of plate, screen, and control-grid currents the formula (see computor) says to add up the above values but use only one-half of the A values (giving 250 ma for plate, 100 ma for screen, and 40 ma for grid), and then divide by 12, as follows:

D-C meter reading = 1/12 (0.5 A+B+C+D+E+F)

	Plate	Screen	Control grid
	250 ma	100 ma	40 ma
	500	155	70
	450	60	42
	300	15	17
	90	0	0
	0	0	0
Total	1590 ma	330 ma	169 ma
D-C current = 1/12 total = (approximately)	133 ma	28 ma	14 ma

Now, to caculate the r-f output power it is necessary to use the formula for the peak r-f current which is present in the tube plate current. Since we are using the tube as a straight r-f power amplifier, we use the formula for "Peak Fundamental R-F" as shown on the computor. (If we were estimating the performance of a doubler or tripler we would use the formula for "Peak 2nd Harmonic R-F "or "Peak 3rd Harmonic R-F".)

From the computor we see that the formula for the peak fundamental r-f current is:

1/12 (A+1.93B+1.73C+1.41D+E+0.52F)
A= 500=500 ma
1.93B=1.93 x 500=965
1.73C=1.73 x 450=778
1.41D=1.41 x 300=423
E= 90= 90

Total =2756 ma
Peak fundamental current=1/12 total
=2756/12=230 ma

We now have the various current values. In order to calculate the powers involved, it is necessary to know not only the d-c voltage values but the greatest amount each voltage swings away from the d-c value. This is known as the peak value of the r-f voltage. Because the plate voltage swings from 2000 volts down to 250 volts the peak r-f plate voltage is the difference, or 1750 volts. Similarly the grid voltage must rise and fall between the operating points No. 1 and No. 2, or from −130 volts to +90 volts. This is a peak swing of 220 volts and the peak r-f grid voltage is 220 volts.

Let us now use the formulas for output power and driving power:

Output power = ½ peak r-f plate current x peak r-f plate voltage.

We found the peak r-f plate current to be 230 ma or .230 ampere, and the peak r-f plate voltage to be 1750 volts.

So; Output Power = ½ x 0.230 x 1750 = 201 watts,
and Input Power = D-C Plate Current x D-C Plate Voltage
= 0.133 x 2000 = 266 watts
Plate Dissipation = D-C Input Power — R-F Output Power
= 266 — 201 = 65 watts
Efficiency = R-F Output Power divided by D-C Input Power
= 201/266 = 75.5%
Driving Power = D-C Grid Current x Peak R-F Grid Voltage
= 0.014 x 220 = 3.1 watts

The power consumed by the bias source is simply the product of the d-c grid current and the d-c grid voltage, or 0.014 x 130 = 1.7 watts.

The difference between the driving power and the power consumed by the bias source is the power dissipated on the control grid, or 3.1 — 1.7 = 1.4 watts.

The power dissipated on the screen grid is simply the product of the d-c screen current and the d-c screen voltage because the screen grid has no impedance between it and the d-c screen supply. Thus it is 0.028 x 250 = 7.0 watts.

The performance of the tube can now be summarized:

D-C Plate Voltage	2000 volts	Driving Power	3.1 watts
D-C Screen Voltage	250 volts	Grid Dissipation	1.4 watts
D-C Grid Voltage	—130 volts	Screen Dissipation	7.0 watts
D-C Plate Current	133 ma	Plate Input Power	266 watts
D-C Screen Current	28 ma	Plate Output Power	201 watts
Peak R-F Grid Voltage	220 volts	Plate Dissipation	65 watts

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